

Leachate Characterization and Synthetic
Leachate Formulation for Liner Testing

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ABSTRACT

A U.S. EPA sponsored study was conducted to characterize leachates from hazardous waste land disposal sites and to assess the feasibility of formulating a multi-compound synthetic leachate for liner testing. Leachate samples from 13 hazardous waste disposal sites were analyzed for priority pollutant compounds, total cyanide, total organic carbon, chemical oxygen demand, and various other parameters.

The analytical data were evaluated to characterize the occurrence, frequency and concentrations of detected constituents in the leachates. Conclusions were made regarding the feasibility of formulating a synthetic leachate based on the study data. Recommendations were made to approaches to representing constituents in a leachate formulation and for follow-up analytical programs which would more comprehensively characterize leachates and enlarge the organic constituent data base.

INTRODUCTION

The Hazardous Waste Engineering Research Laboratory (HWERL) of the U.S. EPA is developing a data base containing information on a variety of hazardous wastes and associated leachate compositions. The data base is required to assess the feasibility of formulating multi-compound synthetic hazardous waste leachates for testing containment liners under consideration for use in landfills and other hazardous waste storage, treatment, and disposal facilities. Liner and chemical compatibility experiments generally have involved testing only a single chemical compound or waste. Therefore, any synergistic effects on liners that might be caused by hazardous waste leachates which are, in fact, multi-compound and generated from complex waste mixtures are relatively unknown.

The U.S. EPA sponsored a study in 1985 to gather data on the composition of leachates generated by operating hazardous waste disposal sites. An assessment was made regarding the feasibility of formulating a synthetic leachate based on the study data. The data can also be used by other researchers in predicting the chemical compositions of leachates generated by various hazardous wastes and for use as a general reference on leachate composition.

This paper presents the study approach, selected results, and recommendations for both synthetic leachate formulation and follow-on analytical programs. Another U.S. EPA sponsored study which incorporates some of these recommendations was initiated in June of 1986. The results of this new study were not available at the writing of this paper.

DESCRIPTION OF SITES SELECTED FOR LEACHATE COLLECTION

The leachate samples characterized during this study were collected from 13 professionally operated hazardous waste landfills. These sites were selected from a master list of 43 operating landfills which accepted either only hazardous wastes or a combination of municipal and hazardous wastes. Besides site willingness to participate, criteria for site inclusion in the study involved consideration of the following:

1. Existence of a leachate collection system and system accessibility for sample collection.
2. Period of site operation, i.e., for five years or at least long enough to generate leachate at a sufficient rate for sample collection and at a quality representative of disposal wastes.
3. Available and reliable information regarding the types of wastes disposed at the site.
4. Contribution to an overall site profile which illustrated waste type, geographic, and climatic diversity.

One objective of the study was the generation of a data base which represented a wide spectrum of existing leachate characteristics. The available sites which were finally selected for inclusion were located in various geographic locations of the United States, thereby representing to some degree varying climatic conditions. The sites also varied in the relative quantities, types, and physical forms of the wastes accepted for disposal (e.g., containerized liquids versus bulk solids); the landfill disposal operating practices (e.g., cover material and frequency of cover application); and the period of site operation. All of these factors plus others can interrelate and impact the generation rates and chemical characteristics of the respective

leachates. Table 1 provides an overview of the 13 sites finally selected for leachate sampling and analysis.

LEACHATE SAMPLE COLLECTION AND ANALYTICAL PARAMETERS

Collection of leachate samples for each of the 13 sites occurred between June 9 and 21, 1985. Sample collection was conducted as close as possible to the generation source in order to maximize sample representativeness of actual leachate quality. However, points of collection varied depending on system design and leachate accessibility. Sample collection points included leachate collection system sumps, bleeder valves, pipe discharges into drainage channels, recently filled storage tanks, and, in one case, a storage lagoon.

Field tests (i.e., pH, temperature, redox potential, and specific conductance) were performed on-site. Laboratory analyses included tests for volatile organics; semi-volatile organics, including acid and base/neutral extractables; heavy metals; cyanide; total organic carbon; and chemical oxygen demand.

Laboratory analyses involved standard U.S. EPA procedures and protocols. Samples for the organic analyses had to be diluted five or ten times in order to reduce their high chemical concentrations to testable levels. A 24-hour continuous liquid/liquid solvent extraction system was used during the analyses of semi-volatile organics rather than the separation funnel technique in order to avoid emulsion formation.

Table 1.
Overview of Thirteen Sites Selected
for Leachate Sampling and Analysis

Site Number	Site Age (Years)*	Waste Type Input*	Geographic Location in the U.S.	Net Precipitation Range (Inches)
1	3	Alkaline inorganics; liquids and solids; 40% drummed/60% bulk	Southern	-10 to +5
2	3	Variety, specifics not available; all bulk solids	Southern	+10 to +15
3	5	Wide variety; inorganic and organic; solids only, drummed and bulk	Southern	+5 to +10
4	4	Wide variety; organic concentrations < 5%; solids only; 25% drummed/75% bulk	Central	-10 to +5
5	5	Wide variety; inorganic and organic; mostly containerized solids and liquids	Western	< -10
6	3.5	Variety; mostly petrochemical and electroplating wastes; solids only; drummed and bulk	Western	< -10
7	6	95% wastewater treatment sludge; some drummed liquids	Northeastern	+5 to +10
8	7	65% wastewater biological treatment sludge, 18% phthalate/benzyl chloride wastes; 15% lime grit; bulk solids only	Northeastern	+5 to +10
9	13	Variety; inorganic and organic; drummed non-halogenated solvents and oily residues; bulk pigments	Northeastern	+10 to +15
10	2	Variety; including incinerator and refinery wastes, asbestos, fly ash; drummed and bulk, no free liquids	Central	-10 to +5
11	10	Wide variety; organic and inorganic, drummed and bulk	Northeastern	+5 to +10
12	5	70% PCB-containing materials, 29% wastewater treatment sludge, 1% cyanides and corrosives; 20% drummed/80% bulk	Central	+5 to +10
13	5	Wide variety; inorganic and organic; solids only; drummed and bulk	Southern	+10 to +15

*This information is only for the sampled portion of a site.

OVERVIEW OF THE ANALYTICAL RESULTS

The data generated from the analyses of the leachate samples during this study is too extensive to present completely in this paper on a sample-specific basis. However, general information regarding the occurrence of the components and the ranges of certain parameter levels will be presented. A report which presents the details and complete results of this study was submitted to the U.S. EPA in September 1985 and will be made available to the public. (1)

Field Tests and COD Data Results

Sample temperature, pH, redox potential, and specific conductance were measured at the time of sample collection. Data for these parameters, however, were not considered reliable for every site because of suspected field instrument malfunction.

Leachate temperature was measured at 5 of the 13 sites and ranged from 20 to 32°C, with a mean of 27°C and a standard deviation of 6.2°C. The parameter of pH was measured at 5 sites and ranged from 7.1 to 9.3, with a mean of 8.2 and a standard deviation of 0.857. Redox potential was measured at only 3 sites and was recorded as -0.343, -0.241, and -0.093.

Specific conductance was measured at 9 of the 13 sites. Specific conductance greater than 20,000 micromhos per centimeter was measured in samples from Sites 4, 6, 8, and 10. The specific conductance of samples from the other 5 sites ranged from 4,250 to 12,000 micromhos per centimeter.

Laboratory analysis for COD was performed on samples from all of the sites. The results ranged from 1,950 to 23,300 ppm, with a mean of 10,217 ppm and a standard deviation of 6,475 ppm. Samples from Sites 3, 4, 5, 6, 7, and 9 had COD measurements of less than 10,000 ppm.

Inorganic Data Results

Each of the 13 samples were analyzed for metal priority pollutants including silver, arsenic, beryllium, nickel, lead, cadmium, copper, mercury, antimony, selenium, thallium, and zinc. Most of the metals were detected in every sample, except mercury, antimony, thallium, and beryllium. Generally, the metals were detected only in the low or fractional parts per million (ppm) range. Beryllium was the least commonly detected metal and was detected only in samples from six sites.

Arsenic and selenium were the most common of the metals detected at least once at levels greater than one ppm, being detected in samples from 7 sites each, followed by nickel and zinc in 5 samples each, and copper in 4 samples. The samples collected from Sites 1, 3, 6, and 12 contained 5 or more metals at concentrations greater than 1 ppm, including selenium and zinc in all cases.

Total cyanide was detected in samples from 9 sites. Cyanide levels ranged from 0.01 to 55 ppm. Five of the leachate samples contained total cyanide at levels less than one ppm. The highest levels of total cyanide were 27.6, 40, and 55 ppm and were detected in samples from Sites 11, 1, and 3, respectively.

Total Organic Carbon Results

Total organic carbon (TOC) was determined to gauge how successfully analysis had identified the organic constituents. The constituents have been comprehensively identified if analytical TOC equals the calculated TOC of the whole sample, based on measured combined quantities of individual organic compounds.

The analytical TOC values ranged from 195 to 11,750 ppm. The percentage of the analytical TOC which was accounted for was less than 10 percent for 11

of the 13 leachate samples and less than 5 percent for 6 of the 13 samples. A substantially larger percentage of the analytical TOC was accounted for by the calculated TOC in samples from Sites 5 and 9, 40.4 and 59.5 percent, respectively. These samples also had the lowest analytical TOC values at 195 ppm (Site 5) and 309 ppm (Site 9).

The low percentage of analytical TOC accounted for reflects substantial concentrations of non-volatile low or high molecular weight organics or other constituents which do not extract or successfully chromatograph using routine and standard analytical methods. Three other possible explanations for the low accountability of TOC include:

1. The incomplete extraction of water soluble semi-volatiles may have occurred during sample preparation.
2. A combination of sample concentration (very high in organics) and sample complexity (a large number of diverse compounds) may have caused misidentification of compounds. The occurrence of this is probably unlikely because the mass spectrometric results were computer matched. However, GC peak overlap was observed and even with the identification of peak components by mass spectrometry concentration errors may not have been avoided.
3. The GC/MS methodology was highly sensitive and most of the leachate samples contained a large organic component. Therefore, the samples required large dilutions in order to keep the readings on scale. These dilutions increased the minimum detection limits for the compounds, which ranged from as little as 25 ppb to as much as 10,000 ppb. As a result, many trace constituents which may have been detectable in an undiluted sample were rendered undetectable by the large dilutions.

Organic Data Results

The leachate samples were analyzed for 35 volatile and 68 semi-volatile organic priority pollutants. In addition to the detected priority pollutants, 84 non-priority pollutant compounds and families of compounds were identified by the matching of GC/MS spectra with a library compiled from National Institute of Health and U.S. EPA libraries.

All of the detected organic compounds were grouped into the six general classes of organic compounds which are frequently used to discuss the compatibility of chemicals with various containment liners. These classes included organic acids, oxygenated/heteroatomic hydrocarbons, halogenated hydrocarbons, organic bases, aromatic hydrocarbons, and aliphatic hydrocarbons.

The overall characterized TOC on average equated only about four percent of the total sample analytical TOC. Assignment of this characterized amount to the six classes mentioned above (based on mole fraction) is as follows (in decreasing order): organic acids - 39.0 percent, oxygenated/heteroatomic hydrocarbons - 35.8 percent, halogenated hydrocarbons - 11.0 percent, organic bases - 7.2 percent, aromatic hydrocarbons - 6.0 percent, and aliphatic hydrocarbons - 0.9 percent. In general, the classes containing compounds with relatively high aqueous solubilities accounted for higher mean mole fraction percentages than did the classes containing compounds with lower aqueous solubilities.

A summary of the leachate organic compound occurrence data is presented in Table 2. The following observations were made based on all of the data:

1. Organic acids, as a class, were approximately 55 percent (by mole fraction) phenol and substituted phenols and 45 percent carboxylic acids, including benzoic acid and alkanolic acids with 4 or more carbon atoms. The compounds detected in leachate samples from the greatest number of the sites were phenol (13 sites), 4-methylphenol

Table 2.
Summary of Leachate Organic Chemical
Occurrence Data

Chemical Classification	Percent Occurrence (Total Mean Mole Fraction)	Representative Chemical(s) and Occurrence (Total Mean Mole Fraction)
Organic Acids	39.0%	Phenol (11.8%) Substituted Phenols (17 compounds at 9.5%) Benzoic Acid (5.3%) and Substituted Benzoic Acids (4 compounds at 0.1%) Alkanoic Acids (13 compounds at 12.3%)
Oxygenated/Heteroatomic Hydrocarbons	35.8%	Acetone (16.5%) Common Ketone Solvents, e.g., 2-Hexanone, 2-Butanone, and 4-Methyl-2-pentanone (9.2%) Alcohols of all types (16 compounds at 8.1%)
Halogenated Hydrocarbons	11.0%	Methylene Chloride (6.8%) Chlorobenzenes (4 compounds at 1.4%) Multichlorinated Alkanes/Alkenes (10 compounds at 2.8%)
Organic Bases	7.2%	Aniline (2.9%) and Substituted Anilines (6 compounds at 1.4%)
Aromatic Hydrocarbons	6.0%	Toluenes (4.2%) Benzene and Alkyl-substituted Benzenes (except Toluenes) (1.4%)
Aliphatic Hydrocarbons	0.9%	This group did not have any good representatives in terms of level of occurrence.

(12 sites), 2-methylphenol (10 sites), 2,4-dimethylphenol (9 sites), and benzoic acid (8 sites).

2. The oxygenated/heteroatomic hydrocarbons, as a class, were approximately 46 percent acetone, 26 percent common ketone solvents, and 23 percent alcohols. The compounds detected in samples from the greatest number of sites were acetone (13 sites), 2-hexanone (13 sites), 2-butanone (12 sites), 4-methyl-2-pentanone (11 sites), and di-n-butylphthalate (9 sites). Methanol or ethanol was not detected in leachate from any site. The various ethers, esters, and aldehydes were infrequently detected in low concentrations. These three groups were not well represented by any particular compound.
3. Methylene chloride accounted for approximately 61 percent of the halogenated hydrocarbon occurrences. Dichlorinated benzenes and chlorobenzene accounted for about 13 percent, but these compounds were generally not widely distributed; and only occurred at less than half of the sites. The compounds detected in samples from the greatest number of sites were methylene chloride (13 sites) trichloroethylene (11 sites), chloroform (10 sites), tetrachloroethylene (7 sites), and chlorobenzene (6 sites).
4. Organic bases were present in leachates from nine sites. A single organic base did not occur at half or more of the sites. Although aniline ranks first by a large margin in the mean mole fraction percentage represented, it was detected in samples from only 3 of the 13 sites sampled.

5. Toluene, benzene, and other alkyl-substituted aromatics accounted for approximately 92 percent of the aromatic hydrocarbon class. The aromatic hydrocarbons detected in samples from the greatest number of sites were toluene (13 sites), benzene (12 sites), total xylenes (11 sites), ethylbenzene (10 sites), and naphthalene (4 sites). Toluene ranks first by a large margin in the mean mole fraction percentage represented.
6. Aliphatic hydrocarbons occurred infrequently and were only detected in samples from 3 of the 13 sites.

Pesticide Data Results

Analytical Method 625 for semi-volatile organics was used to screen for PCBs and pesticides in all of the samples. Detected levels were negligible in terms of mole fraction percentage for all types of organic compounds. A GC/ECD analysis for PCBs and chlorinated pesticides was also carried out on the sample from Site 12, at which 70 percent of the wastes were PCB-contaminated materials. Seven different PCBs and pesticides were detected in the sample. In order of concentration from highest to lowest and in parts per billion, the compounds were: endosulfan sulfate (14.8), endrin ketone (11.4), heptachlor epoxide (8.6), dieldrin (4.5), 4,4'-DDD (2.2), endrin (1.9) and alpha-BHC (1.7). The combined contribution of these substances was negligible at less than 0.01 mole fraction percentage. In addition, the above compounds accounted for only a very small part of sample analytical TOC.

RECOMMENDATIONS REGARDING SYNTHETIC LEACHATE FORMULATION

The results of this study do not collectively characterize any particular leachate which was generated by any particular waste or land disposal unit.

Instead, as intended, the occurrence data represents an integration of leachate qualities found to be exhibited by a variety of professional operating hazardous waste landfills. A synthetic leachate for actual testing of liners could not be formulated based on a four percent characterized organic fraction. Organic compounds that exist within the 96 percent of uncharacterized TOC can impact the effectiveness of liners and thus deserve to be represented in a synthetic leachate. Nevertheless, useful information about the composition of actual leachates has been revealed, particularly with respect to the relative distribution and representation of the six organic classes. Additionally, recommendations can be made in regards to approaches for future studies which would generate a more complete data base on organic constituents.

The study did characterize completely the concentrations of priority pollutant metals in the various leachates, finding that the most common metals were arsenic, selenium, nickel, and zinc. Additionally, other parameters were quantified for many of the samples and demonstrated a range of values. Nevertheless, liner compatibility tests have shown that heavy metals in saturated solutions are generally compatible with flexible membrane liners and that inorganic constituents mostly affect only soil and clay materials. (2,3) Additionally, reference materials regarding the importance of cyanide, redox potential and COD with respect to leachate and liner compatibility are scarce. Liner compatibility tests have been demonstrated that even minor amounts of dissolved organics can be particularly aggressive to synthetic liners, thereby dissolving the components and causing failure. (3) Most, if not all, liner materials are also affected by very high or very low pH values. For all of these reasons, only guidelines for the selection of organics and pH levels are recommended.

The pH values which were reported during this study ranged from neutral to mildly alkaline. Based on these results, a value range of 7 ± 2 is proposed as a reasonable pH for a synthetic leachate.

A synthetic leachate should also be approximately 99 percent aqueous and 1 percent organic by weight. This estimate is based on an analytical average TOC of about 0.3 grams per 100 milliliters of sample, or about 0.3 percent carbon. This amount of carbon would produce a weight of 1 gram (or less) of organic compounds per 100 milliliters.

Several approaches can be taken toward the formulation of a synthetic leachate, once a sufficiently complete data base is generated on the organic constituents of actual hazardous waste leachates. Tables 3 and 4 present examples for three such approaches by using the results of this study. These formulas should be viewed only as prototypes, intended only to illustrate possible approaches to leachate formulation, and not as strict examples of what constituents and concentrations should be in such formulations.

Table 3 presents a synthetic leachate formula which is generic in that it simply proposes at what proportions the organic classes should be represented, as supported overall by a data base. Each organic class is represented by only a few specific compounds, such as those given in the table as examples, at the respectively appropriate mole fraction percentage. The constituents and class proportions should be supported by representations in the data base. Based on the results of this study and as presented in the table, the organic acid group consists of representative phenols and carboxylic acids in approximately equal proportions with respect to mole fraction. The oxygenated/heteroatomic group consists of representative ketones and alcohols, in a ratio of about two to one, respectively.

Table 3.
Example of a Generic Synthetic Leachate Formulation

Chemical Type	Example(s)	Mole Fraction Percentage
ORGANIC ACIDS		
Phenols	Phenol, Cresols	21
Carboxylic Acids	Benzoic, Hexanoic	18
OXYGENATED/HETEROATOMIC HYDROCARBONS		
Ketones	Acetone, 2-Butanone, 4-Methyl-2-pentanone	26
Alcohols	Benzyl, Hexanol	10
HALOGENATED HYDROCARBONS	Methylene Chloride, Chlorobenzene	11
ORGANIC BASES	Aniline	7
AROMATIC HYDROCARBONS	Toluene, Benzene	6
ALIPHATIC HYDROCARBONS	Heptadecane	1

Table 4.
Examples of Two Specific Synthetic
Leachate Formulations

Compound	Compound Contribution as a Mole Fraction (m.f.) Percentage	
	Synthetic Leachate A Chemicals Occurring at ≥ 5 Sites	Synthetic Leachate B Chemicals Occurring at Average Concentrations ≥ 1.0 m.f. (x100)
ORGANIC ACIDS		
Phenol	12%	12%
4-Methylphenol	6%	6%
2-Methylphenol	3%	5%
2,4-Dimethylphenol	2%	—
2-Methylpropanoic Acid	—	1%
Benzoic Acid	6%	6%
Phenylacetic Acid	5%	—
Butanoic Acid	—	4%
Pentanoic Acid	—	3%
Hexanoic Acid	—	2%
2-Ethylhexanoic Acid	5%	—
Subtotal	39%	39%
OXYGENATED/HETEROATOMIC HYDROCARBONS		
Acetone	17%	16%
2-Butanone	5%	7%
2-Hexanone	3%	4%
4-Methyl-2-pentanone	2%	—
Di-n-butylphthalate	1%	—
Benzyl Alcohol	8%	8%
Subtotal	36%	36%
HALOGENATED HYDROCARBONS		
Methylene Chloride	5%	9%
Chlorobenzene	1%	—
1,2-Dichlorobenzene	—	2%
Chloroform	1%	—
Tetrachlorethylene	1%	—
Trichlorethylene	1%	—
1,1,1-Trichloroethane	1%	—
trans-1,2-Dichloroethylene	1%	—
Subtotal	11%	11%
ORGANIC BASES		
Aniline	—	3%
N,N-Dimethylacetamide	—	4%
4-Methylbenzenesulfonamide	7%	—
Subtotal	7%	7%
AROMATIC HYDROCARBONS		
Toluene	3%	6%
Ethylbenzene	1%	—
Xylene(s)	1%	—
Benzene	1%	—
Subtotal	6%	6%

Table 4 presents two synthetic leachate formulas which are more chemically complex and specific than the generic formula of Table 3. Each organic class is still represented in the formulas by that proportionate amount supported by the overall data base, but many more chemicals are selected to represent each class. The specific formulas differ based on the criteria used to select the chemicals and the respective proportions. The criteria for chemical inclusion in Synthetic Leachate A is the frequency of chemical occurrence in samples, i.e., a chemical is included if it was detected in leachates from five or more sites. The criteria for chemical inclusion in Synthetic Leachate B is the detected concentration of a chemical, i.e., a chemical is included if it was detected at average concentrations greater than 1.0 mole fraction percentage. Chemical class and chemical proportionate contributions to the synthetic leachate are shown in the table by a mole fraction percentage and should again be dependent on the supporting data.

The leachate samples collected during this study were approximately one percent organic by weight. Organic concentrations can vary with time and location within a site as the wastes age and change in composition. Additionally, a punctured and corroded container can result in a localized and highly concentrated organic contact with a liner. Compatibility tests which use a synthetic leachate containing an organic portion much greater than one percent may be performed to represent such a situation.

RECOMMENDATIONS REGARDING ANALYTICAL PROGRAMS FOR SIMILAR STUDIES

Subsequent leachate characterization studies should ideally include analytical programs which employ state-of-the-art techniques designed to more fully characterize the organic materials. Studies should initially be limited

in scope to characterizing leachates from one or two facilities and thereby first evaluating the adequacy of any proposed analytical program. The analyses of samples from sites which accept a wide variety of waste types, such as commercial facilities, would probably best gauge a program's ability to identify a variety of compounds.

Based on what was observed regarding the limitations of this study's analytical scheme, the following approaches are recommended with regard to subsequent studies:

1. Total recoverable oil and grease analyses could be performed on the samples to improve the mass balance results (i.e., the agreement between analytical and calculated TOC). This information could be very helpful in characterizing at least part of the organic fraction.
2. In addition to carrying out oil and grease extractions, other separation procedures could be attempted. Silica gel column chromatographic separation into polar, aromatic, and aliphatic fractions before GC/MS analysis would permit better separations by GC and more reliable identification by MS. Also, a TOC or oil and grease analysis on an aliquot of each column chromatographic fraction would allow an assessment of material balance during analysis.
3. Alternatively, general chemical classes could be analyzed, rather than specific organic compounds. For instance, total organic halogen, total phenols, and oil and grease could be included as key parameters.
4. A percent water determination could be performed on the sample. This procedure would give direct information about the extent of the aqueous portion of the leachate.

5. A determination of whether the leachate sample is homogenous or whether it has a separable organic fraction that either floats or sinks could be made. This factor would determine whether or not a mainly aqueous phase or a mainly organic phase is in contact with the liner. An analytical scheme could be then developed, if preferred, only for that phase in contact with the liner.

At the writing of this paper, another U.S. EPA-sponsored study is underway which incorporates some of the above recommendations. This effort's analytical scheme will hopefully more fully characterize the organic content of leachate. The first phase of this new study involves the application of the analytical program to one sample to gauge its effectiveness. Changes may be made to this program's scope before its application to two additional samples if the initial results are not satisfactory.

CONCLUSION

The routine analyses of 13 hazardous waste leachate samples resulted in a complete characterization of priority pollutant metals and the incomplete characterization of organic constituents. However, the results did provide valuable information regarding the relative distribution and representation of six organic classes.

Nevertheless, a synthetic leachate could not be formulated based on these results alone. However, several approaches can be suggested regarding the selection and relative concentrations of constituents in a synthetic leachate formula for consideration once a sufficient data base is available. Such approaches might include the development of a generic formula in which each organic class is represented by a few of the compounds most commonly encountered in actual leachates. Other approaches might include developing

formulas in which many more chemicals are represented. The criteria for chemical inclusion in these more specific formulas might be based on whether the chemicals frequently occurred in a number of actual samples or on whether the chemicals were detected above a certain proportionate concentration.

Future studies should employ an analytical program which is specifically designed to more comprehensively characterize the organic components of actual leachates. This approach is particularly relevant with respect to formulating synthetic leachates for liner compatibility studies because organics have been shown to be particularly aggressive agents toward such liners. A study which incorporates such an analytical program is currently underway and is being sponsored by the HWERL of the U.S. EPA.

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